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EFFECTS OF INITIAL ABSTINENCE AND PROGRAMMED LAPSES ON THE RELATIVE REINFORCING EFFECTS OF CIGARETTE SMOKING

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Fifty-eight smokers received abstinence-contingent monetary payments for 1 (n = 15) or 14 (n = 43) days. Those who received contingent payments for 14 days also received 0, 1, or 8 experimenter-delivered cigarette puffs on 5 evenings. The relative reinforcing effects of smoking were assessed in a 3-hr session on the final study day, when participants made 20 choices between smoking or money. The reinforcement contingencies exerted robust control over smoking, and programmed smoking lapses produced few discernible effects. These results further illustrate the robust control that reinforcement contingencies can exert over cigarette smoking and suggest that any effects of lapses on the relative reinforcing effects of smoking are modest under conditions involving abstinence-contingent reinforcement contingencies.

DESCRIPTORS: abstinence, cigarette smoking, contingency management, lapses, reinforcing effects

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Cigarette smoking is the leading cause of preventable morbidity and mortality in the U.S., contributing to approximately 438,000 premature deaths yearly ("Annual Smoking-Attributable Mortality," 2005). Each year millions try to quit smoking, but the majority fails within only a few days or weeks of the cessation effort ("Cigarette Smoking Among Adults," 2005; Garvey, Bliss, Hitchcock, Heinold, & Rosner, 1992; Hughes et al., 1992; Hughes, Keely, & Naud, 2004).

In a seminal study on predictors of smoking-cessation outcomes, Kenford et al. (1994) reported on data from two independent randomized clinical trials on the efficacy of active versus placebo transdermal nicotine therapy (i.e., the nicotine patch). Smoking status during the first 2 weeks of treatment, especially Week 2, was a robust predictor of smoking status at end of treatment and at 6-month follow-up in both studies. In the active patch conditions, for example, more than 80% of those who reported any smoking during Week 2 were smoking at 6-month follow-up. By contrast, 41% to 46% of those who abstained during Week 2 were still abstinent at follow-up. The authors gleaned two prediction rules from their findings: (a) "Any smoking in the first 2 weeks of treatment predicts both short-term and long-term failure," and (b) "Total abstinence during the first 2 weeks of treatment was consistently correlated with sustained smoking success" (p. 593).

Some aspects of this relation between initial abstinence and relapse risk are almost surely due to individual differences and not to dynamic changes in relapse risk during the cessation effort. Regarding individual differences, on average, those with more frequent smoking or greater dependence would be expected to relapse earlier than individuals without those characteristics, thereby assuring a decrease in relapse risk over time. That said, individual differences alone likely fail to offer a complete explanation for these relations between initial and later abstinence. It also seems likely that

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changes in factors that affect ability to abstain occur as a direct result of initial abstinence. Such changes in these factors may, in turn, make it more likely that a person will continue to abstain, thereby facilitating longer term abstinence. For example, the intensity of nicotine withdrawal decreases substantially during the initial weeks of smoking abstinence (Alessi, Badger, & Higgins, 2004; Hughes, Higgins, & Hatsukami, 1990). Although such dynamic changes during an initial period of abstinence may act to directly lower relapse risk, rigorous experimental research examining this topic has been largely missing from the field.

An important obstacle to conducting such experimental research has been the challenge of gaining experimental control over the duration of prior abstinence. Without such control, the influences of dynamic changes that occur during initial abstinence risk being confounded with individual differences among those who achieve different durations of initial abstinence. Previous research has attempted to surmount that obstacle by using contingency management to gain experimental control over abstinence (Alessi et al., 2004; Heil, Alessi, Lussier, Badger, & Higgins, 2004; Lussier, Higgins, & Badger, 2005; Roll, 2005; Yoon, Higgins, & Bradstreet, 2007). Researchers have also focused on investigating relations between early and later smoking abstinence among smokers who are willing to try to quit as part of a study but are not now trying to quit longer term (e.g., Stitzer, Rand, Bigelow, & Mead, 1986). Using this target population increases the likelihood that any changes in smoking frequency are due to the experimental variables under investigation as opposed to individual reasons for wanting to quit that may be unstable over time.

In a prior study addressing how early abstinence influences later abstinence, contingency management in the form of monetary payments delivered contingent on biochemically verified smoking abstinence was used to create different histories of prior abstinence such that participants either largely abstained during three 5-day experimental periods or abstained only during the last of those periods (Heil et al., 2004). Abstinence levels during the third period were significantly higher in those with a history of abstaining compared to those who were abstaining for the first time, suggesting that a history of prior abstinence facilitated later abstinence.

An important next step in this series of studies included a direct test of the relative reinforcing effects of smoking following different durations of smoking abstinence (Lussier et al., 2005). Study participants were randomly assigned to receive abstinence-contingent payments for either 1 day (1C), 7 days (7C), or 14 days (14C) and then completed a 3-hr test of the relative reinforcing effects of smoking. The test involved participants making a maximum of 20 discrete-trial choices between earning two puffs on a cigarette or \$0.25. Results indicated that the relative reinforcing effects of smoking were significantly lower among those assigned to the 14C compared to the 7C and 1C conditions. That is, participants in the 14C ($M = 0.52$, $SEM = 0.28$) condition made significantly fewer choices of the smoking option than those in the 7C ($M = 2.19$, $SEM = 0.60$) or 1C ($M = 2.71$, $SEM = 0.63$) conditions, and a smaller proportion of participants in the 14C (19%) condition chose to smoke at least once compared to those in the 7C (57%) and 1C (62%) conditions. The differences in smoking preference as a function of different durations of smoking abstinence noted by Lussier et al. were recently replicated in a follow-up study also conducted in our laboratory (Yoon et al., 2007).

In the present study we sought to extend these prior observations by examining the effects of programmed smoking lapses during the initial 2 weeks of smoking cessation on the relative reinforcing effects of smoking. Although smoking even a few puffs on a cigarette during a cessation effort has been reported to increase the probability of relapse (Kenford

et al., 1994), there has been little experimental analysis of this association between brief smoking lapses and relapse risk. This study represents an effort to examine in a controlled setting how such lapses may increase the probability of relapse. Examining how lapses may interfere with dynamic changes in factors such as withdrawal level, mood, relative reinforcing effects of smoking, and so on that occur during initial abstinence may provide insight into how to devise more effective interventions for the early hours and days of a quit attempt when the vast majority of relapse back to smoking occurs.

METHOD

Participants

Participants were 63 adult smokers (31 male, 32 female) who were recruited via local newspaper ads and fliers on bulletin boards at local colleges and in the general community. Of these participants, 58 (27 male, 31 female) completed the study and were included in data analyses. Among the 5 who did not complete the study, 2 were excluded for using nicotine replacement during the course of the study, 2 left the geographic area during the course of their participation, and 1 was lost to follow-up after Day 1.

Participants were initially screened for study eligibility in a telephone assessment that inquired about physical and mental health as well as smoking and other drug-use histories. All potentially eligible participants were invited to the laboratory to complete an interview during which more detailed medical, mental health, smoking, and other drug use histories were obtained. To be eligible for the study, individuals had (a) to be 18 to 55 years of age, (b) to report smoking at least 10 cigarettes a day for a year or more, (c) to indicate that they were not currently trying to quit smoking, (d) to be in good health, and (e) to provide a breath carbon monoxide (CO) sample $\geq$ 18 ppm. These smoking criteria were used to assure that participants smoked at moderate or higher frequencies relative to U.S. norms ("Cigarette Smoking Among Adults," 2005). Exclusion criteria were current use of psychoactive medications, a history of a major psychiatric disorder, drug or alcohol dependence (excluding nicotine), or being pregnant or lactating. Smokers who were not currently trying to quit were recruited to increase the likelihood that smoking rates were under experimental control rather than variables extraneous to the study (e.g., health concerns). All participants provided written informed consent and were assigned to the experimental conditions described below.

Procedure

Orientation session. During the orientation session, participants signed consent forms, were introduced to study measures, were trained on the standardized puffing procedure described below, and were informed of the study condition to which they were assigned. Urine samples were collected at the orientation session and on each subsequent study day. Samples were tested once weekly for illicit drug use using an onsite enzyme-multiplied immunoassay technique. Participants were required to test negative for common drugs of abuse (amphetamines, benzodiazepines, cannabis, cocaine, methadone, and opiates) prior to beginning the study and to remain free from illicit drug use throughout the study, because use of psychoactive drugs can change smoking frequency (e.g., Roll, Higgins, & Tidey, 1997). Of all scheduled illicit drug screens conducted during the 14-day study period, 96% were negative for drugs of abuse. Of the 6 participants who tested positive for illicit substances, 5 were positive in one instance, and 1 was positive in two instances.

Abstinence monitoring period. Abstinence monitoring always began on a weekday and continued for 14 consecutive days. Participants attended sessions at the laboratory or at a location convenient for them three times per

day (morning, afternoon, and evening) with a minimum of 4 hr between sessions. At each session, individuals provided a breath CO sample that was analyzed using either PiCO or Micro Smokerlyzer monitors. Participants were informed that we could not specify precisely when they would need to discontinue smoking in order to meet the abstinence criterion (≤ 4 ppm) on their 1st day of contingent payments, but that our recommendation was that they discontinue smoking no later than 5:00 p.m. the day prior to the first scheduled contingent CO assessment (described below).

At each abstinence monitoring session, a breath CO sample was obtained, and the participant was immediately informed of his or her CO level. Money earned was paid in cash either immediately following each CO assessment for those in the abstinence-contingent payment conditions or just prior to each CO assessment for those in the noncontingent payment condition. All participants also reported whether and how much they had smoked since their most recent laboratory visit. Each participant was provided with a free pack of his or her own brand of cigarettes at each morning session. This was done to assure that any abstinence observed was due to contingencies in place, the differential effects of the programmed lapses, and other experimental variables rather than simply because participants ran out of cigarettes.

Experimental conditions and associated payment schedules. Participants were randomized into one of four experimental conditions. In three of these conditions, payments were contingent on abstinence throughout the 14-day abstinence monitoring period (14C). Within the 14C condition, participants were randomized to one of the following three programmed-lapse conditions: (a) no-lapse condition (14C 0-puff), (b) a single-puff/lapse condition (14C 1-puff), and (c) an 8-puff/lapse condition (14C 8-puff; eight puffs are roughly equivalent to one cigarette; Tobin & Sackner, 1982). After 26 participants had been randomized to one of the three 14C conditions, a fourth condition (1C) was added to the study as a control for the abstinence contingency on Days 1 through 13. This 1C condition was comparable to the 1C control condition used by Lussier et al. (2005) and was a no-lapse condition (1C 0-puff). In this condition, payment was independent of smoking status, was yoked to the earnings of someone in the 14C 0-puff condition on Days 1 through 13, and was contingent on meeting the abstinence criterion only on the last day of the study (Day 14). Participants assigned after the 1C condition was added were randomized to any one of the four conditions: 14C 0-puff, 14C 1-puff, 14C 8-puff, or 1C 0-puff.

For those assigned to one of the 14C conditions, abstinence was defined as having a CO ≤ 4 ppm for all sessions except those on the mornings following a lapse session. For CO readings conducted on mornings that followed lapse sessions, the abstinence criterion was ≤ 4 ppm or half the CO reading taken following completion of the lapse session on the previous evening, whichever was higher. This modification in the abstinence criterion was made to protect against money being inadvertently forfeited due to the required smoking in the lapse sessions, but needed to be implemented very infrequently (i.e., fewer than five times total across all participants). The criterion was set back to ≤ 4 ppm for all participants at the afternoon assessment, because the half-life of CO would ensure that even a participant in the 8-puff condition would be able to meet this CO criterion if he or she was otherwise abstaining from smoking (e.g., Henningfield, Stitzer, & Griffiths, 1980).

The payment schedule was identical to that described by Lussier et al. (2005). Briefly, the first time those participants in the 14C condition presented a CO sample indicating abstinence, they received $3.00. Each subse-

quent consecutive CO sample that met the abstinence criterion increased the amount earned by $0.50 up to a maximum of $10.00. Once payment for a negative sample reached $10.00, it remained at that value for each consecutive negative sample. In addition, a $10.00 bonus was earned for every three consecutive CO samples that met the abstinence criterion. If a CO assessment was missed or failed to meet the abstinence criterion, payment was withheld for that sample, and the value of payment available for the next CO sample meeting the abstinence criterion was reset to the initial $3.00 value. To encourage participants to continue trying to abstain following a reset, three consecutive COs meeting the abstinence criterion following a reset returned the payment schedule to the value at which the reset occurred. With this schedule, the maximum amount that participants in the 14C conditions could earn by meeting the abstinence criterion at all 42 visits (three times per day for 14 days) was $507.50.

For participants in the 1C condition, payments were yoked to participants in the 14C 0-puff condition and were independent of smoking status on Days 1 through 13. On Day 14, payments were contingent on meeting the abstinence criterion of CO $\leq$ 4 ppm at the morning, afternoon, and evening sessions. On Day 14, the payment schedule for samples meeting the abstinence criterion began at $10.00 for the first negative sample and remained at $10.00 for each consecutive negative sample; a $10.00 bonus was provided if all three Day 14 samples met the abstinence criterion. As described above, payment was withheld for missed or positive samples, and the schedule was reset to $3.00 for the next negative sample provided. Participants in this condition could earn between $0 and $507.50 for attending all 42 abstinence monitoring visits, with the total amount possible for each participant dependent on the performance of the participant to which he or she was yoked.

To encourage study completion, all study participants received a $50.00 bonus after completion of the study.

Daily participant ratings. All questionnaires were computerized using the CReSS system and were presented on a PC computer. At the initial orientation session and at each evening session during the 14-day abstinence monitoring period, all participants completed a battery of self-report questionnaires that included the Minnesota Nicotine Withdrawal Scale (MNWS, Hughes & Hatsukami, 1986) and a set of visual-analogue items, scaled from 0 (*not at all*) to 100 (*extremely*), that were developed in our laboratory to assess ease of abstaining from smoking and desire to smoke, among other items.

Programmed lapse sessions. Programmed smoking lapse sessions began on Day 5 of the 14-day abstinence monitoring period and occurred every other day thereafter (i.e., Days 5, 7, 9, 11, and 13) for participants in all conditions. Lapse sessions occurred following the evening CO abstinence monitoring assessments on the specified days. All participants were seated alone in private, ventilated rooms (1.22 m by 2.44 m by 2.44 m) that were used only for the lapse sessions. Prior to the lapse session, the experimenter lit a cigarette of the participant's brand and left it burning in the session room. Participants were instructed to leave the cigarette lit and stay in the room until 8 min had elapsed. During lapse sessions, those in the no-lapse conditions (14C 0-puff and 1C 0-puff) were not permitted to take any puffs during the session, and those in the 14C 1-puff and 14C 8-puff conditions were permitted to take one or eight puffs, respectively, at a time of their choosing. Puffs were 60 cc in volume and were delivered according to standardized puffing procedures described below. Five minutes after completing the lapse session, all participants provided a CO sample and were discharged for the evening.

Smoking preference session. Participants completed a 3-hr smoking preference session following the final CO reading on the evening

of Day 14. This procedure has been previously described in detail (Lussier et al., 2005). During the session, participants could make up to 20 exclusive choices between smoking (two 60-cc puffs per choice), obtaining monetary reinforcement ($0.25 per choice), or forgoing both options and simply allowing time in the session to elapse. Including the option to forgo either of the programmed options is necessary for inferring that choices for the smoking or money options are due to their respective reinforcing effects and not because choices were compulsory. During the smoking preference session, participants registered preferences for smoking or money by pulling plungers on a console box that were clearly labeled as the smoking and money plungers. Choices were registered by responding 10 times (fixed-ratio 10) on the corresponding response plunger and were displayed on a monitor in view of the participant. Once the response requirement was completed to register a choice for one option, no additional choices could be registered until 3 min had elapsed. During this interval, participants who chose the smoking option lit a cigarette of their preferred brand without inhaling, and then inhaled two 60-cc puffs on the cigarette, using standardized puffing procedures described below. After completion of the 3-min interval, the smoking and money options were again available until the 20 choices were exhausted. If participants exhausted their 20 choices before 3 hr elapsed, they had to remain in the experimental space for the full 3 hr. This protected against participants who might have another engagement planned after the session from exhausting choices to get an early release.

Participants were instructed going into the preference session that they were free to resume regular smoking beginning with this session, and that doing so would in no way adversely affect their pay aside from the $0.25 that was forfeited per smoking choice during the preference session. Smoking paraphernalia, including an open pack of the participant's preferred brand of cigarettes along with a lighter and ashtray, remained in full view of the participant throughout sessions to increase the probability of smoking and thereby reduce the likelihood of a floor effect in the number of choices made for the smoking option. When not making choices, participants were allowed to read and listen to music on personal stereos. Participants were not permitted to eat, drink, or sleep during sessions. A research assistant was present throughout the session to protect against unauthorized smoking and to directly observe the smoking episode. At the end of the session, participants were paid any money owed to them and discharged.

Standardized puffing procedure. Puffs in the programmed lapse sessions and in the smoking preference sessions were delivered according to a standardized puffing procedure (Zacny, Stitzer, Brown, Yingling, & Griffiths, 1987). Written instructions were presented on a computer monitor and began by directing the participant to inhale approximately 60 cc of smoke. The participant inserted the filter end of a lit cigarette into a plastic cigarette holder that was connected by tubing to a volume sensor and inhaled until a computer-generated tone signaled that the 60-cc volume of smoke had been reached and that he or she was to discontinue inhaling. In the smoking preference session, the computer screen then instructed the participant to hold his or her breath until a 5-s countdown ended. At that time, a second tone signaled to exhale and begin a 25-s interpuff interval, at the end of which the process was repeated for the second puff. In the programmed lapse sessions, the participant was also instructed to inhale the smoke into the lungs, hold the breath for 5 s, and then exhale. To more closely mimic natural smoking patterns, the participant was not required to space puffs 25 s apart during the lapse sessions but was free to space interpuff intervals as he or she wished.

Statistical Methods

Comparisons between the four experimental conditions on participant characteristics were

Table 1
Participant Characteristics

	Experimental condition				
	14C 8-puff (n = 14)	14C 1-puff (n = 15)	14C 0-puff (n = 14)	1C 0-puff (n = 15)	p value
Male (%)	50	47	43	47	.99
Age	21.5 ± 4.1	24.6 ± 8.5	20.6 ± 3.6	25.1 ± 11.4	.32
Caucasian (%)	100	100	100	93	.99
Student (%)	79	60	79	60	.54
Years of education	14.1 ± 2.4	13.5 ± 1.7	13.1 ± 1.3	13.3 ± 1.7	.50
Fagerstrom[a] score	5.1 ± 1.6	5.7 ± 1.0	5.2 ± 1.6	6.1 ± 1.2	.22
No. of cigarettes/day	15.1 ± 4.1	18.5 ± 2.9	17.3 ± 7.6	19.7 ± 4.8	.11
Years smoking at current rate	4.1 ± 3.3	5.9 ± 6.5	3.3 ± 2.8	5.1 ± 7.8	.60
Age of first cigarette use	15.9 ± 2.4	15.3 ± 3.7	14.6 ± 3.2	15.7 ± 1.8	.68
Age of daily cigarette use	16.9 ± 1.9	16.6 ± 3.0	16.5 ± 1.9	17.0 ± 1.6	.94
Nicotine content of usual brand (mg)	0.9 ± 0.2	0.8 ± 0.3	0.7 ± 0.4	1.0 ± 0.3	.11
Baseline CO (ppm)	17.1 ± 0.9	17.5 ± 2.0	19.3 ± 2.1	19.8 ± 1.4	.61
Baseline cotinine (ng/ml)	891.7 ± 138.3[b]	888.1 ± 128.9[b]	1247.6 ± 144.4[bc]	1454.8 ± 132.8[c]	<.01

Note. Values represent means ± *SD*, unless otherwise indicated.
[a] Fagerstrom and Schneider (1989); higher scores represent more nicotine dependence.
[b, c] Denotes significant differences between groups. Means not sharing a common letter are significantly different ($p <$ .05, Fisher's LSD).

performed using one-way analyses of variance for continuous variables and chi-square or Fisher's exact tests for categorical (percentage) variables (see Table 1 for list of variables). Observed baseline differences in cotinine (a metabolite of nicotine) levels were examined further to determine whether they influenced smoking during the abstinence monitoring period (Days 1 to 14) or during the smoking preference sessions. There was no evidence that this variable was predictive of outcomes either within or across experimental conditions; thus, it was not used as a covariate in other analyses.

For participants in the 14C conditions, changes in breath CO from start to finish of the programmed lapse sessions were averaged across the five lapse sessions. To evaluate whether participants in the three 14C conditions were exposed to increasing (or decreasing) amounts of smoking based on puff condition, contrasts representing a linear trend were used to test for ordered changes in breath CO across the three conditions. In addition, t tests were performed within condition on the mean change in CO.

Analyses of data collected during the 14-day study period were conducted separately for Days 1 to 13 and Day 14 due to the change from noncontingent to contingent payments on Day 14 in the 1C condition. For Days 1 to 13, CO was examined as a function of condition (14C and 1C) and session day (1 to 13), using repeated measures analysis of variance. Scores on the MNWS and visual-analogue scales were analyzed using repeated measures analyses of covariance with condition (14C and 1C) and session day (1 to 13) as factors and participants' baseline scores on each measure as covariates. For each measure, the significance of the contrast representing the linear effect was used to test for within-group increasing (or decreasing) trends over time (Days 1 to 13). Tests for main effects were used to assess differences between the two conditions. Analyses corresponding to Day 14 comparisons were performed based on one-way analyses of variance or one-way analyses of covariance. Similar analyses were also performed on the three 14C conditions (14C 0-puff, 14C 1-puff, 14C 8-puff). All means presented are adjusted for the covariate.

For the number of choices in the smoking preference session, contrasts representing a linear trend were used to test for ordered responses across conditions. In addition, possible trends

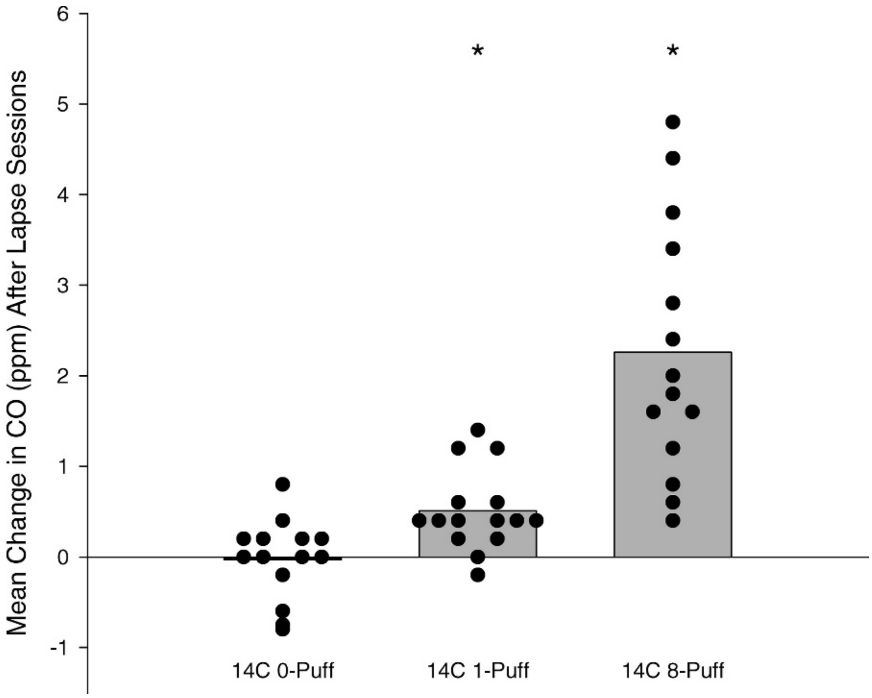

Figure 1. Mean change in breath CO from start to finish of the programmed lapse sessions is shown for each lapse condition (14C 0-puff, 14C 1-puff, 14C 8-puff). Asterisks denote a significant increase in mean CO level from pre- to postlapse with $p < .05$. Individual points represent mean change in breath CO for individual participants.

across conditions in the percentage of participants who chose to smoke during the preference session were examined using Bartholomew's test for order. Trends in both the number of choices and the percentage of participants who chose to smoke were based on the following order of conditions: (a) 14C 0-puff, (b) 14C 1-puff, (c) 14C 8-puff, and (d) 1C 0-puff. Statistical significance was determined based on $\alpha = .05$. Analyses were performed using SAS statistical software Version 8.02.

RESULTS

Baseline Participant Characteristics

There were no significant differences between experimental conditions on participant characteristics assessed at baseline except that baseline cotinine levels were lower among participants in the 14C 1-puff and 14C 8-puff conditions than in the 1C 0-puff condition (Table 1).

Programmed Lapse Manipulation

Changes in breath CO levels from start to finish of the programmed lapse sessions (i.e., CO obtained 5 min after lapse session minus CO obtained just before lapse session) were used to verify that participants in the respective 14C conditions were exposed to varying amounts of smoking. Breath CO increased as a graded function of puff condition, $F(1, 40) = 47.08$, $p < .001$, with significant increases from start to end of sessions being noted in the 14C 8-puff and 14C 1-puff conditions, $t(13) = 6.01$ and $t(14) = 4.40$, respectively, ps $< .01$, but not the 14C 0-puff condition (Figure 1).

Effects of the Reinforcement Contingencies on Smoking Abstinence

The programmed reinforcement contingencies exerted robust control over smoking abstinence. Mean CO levels were consistently below the 4-ppm cutoff in the 14C conditions

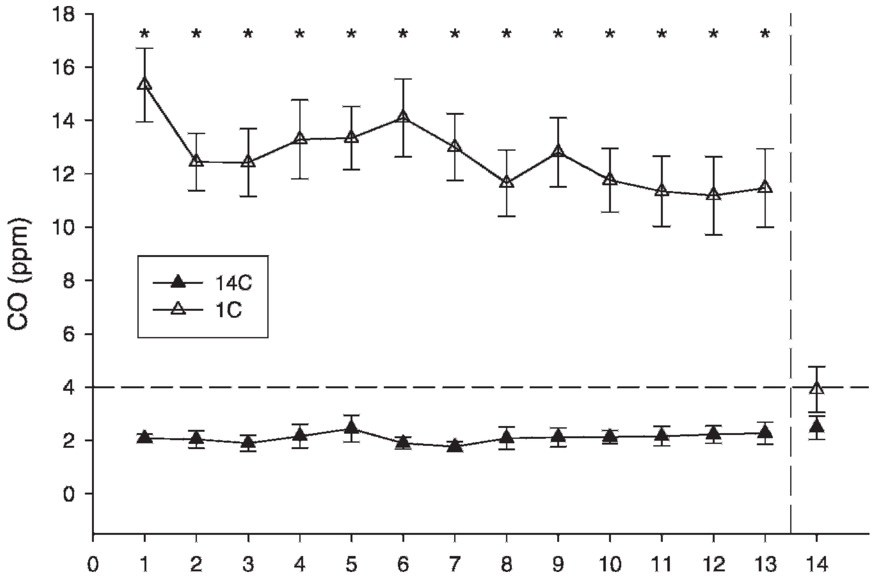

Figure 2. Mean breath CO on Days 1 to 14 is shown for the 14C and 1C conditions. Vertical dotted line between Days 13 and 14 denotes change from noncontingent to contingent payment in the 1C condition. Horizontal dotted line denotes the abstinence cutoff at 4 ppm. Vertical bars represent ± *SEM*. Asterisks denote significant day-specific differences between groups for $p < .05$.

but not the 1C condition across Days 1 to 13 when reinforcement delivery was contingent on smoking abstinence in the former but independent of smoking status in the latter, $F(1, 56) = 173.03$, $p < .01$ (Figure 2). Indeed, 95% (1,585 of 1,677) of all breath CO samples collected from those assigned to the 14C conditions during Days 1 to 13 met the reinforcement criterion compared to only 8% (48 of 585) of those collected during that same period from those assigned to the 1C condition, as reflected in the individual participant data for each condition displayed in Figure 3. When reinforcement delivery for those in the 1C condition was made contingent on smoking abstinence on Day 14, mean CO levels dropped precipitously in that condition as well, providing compelling evidence of control over smoking by the reinforcement contingencies.

Effects of programmed lapses on control over smoking abstinence by the reinforcement contingencies during Days 1 to 13 were examined in two ways, and neither of those analyses revealed any systematic effects. First, we compared abstinence levels on Days 1 to 14 among all participants assigned to the three 14C conditions. There were no discernible differences in mean CO levels across Days 1 to 14, including on Days 6, 8, 10, 12, and 14 that immediately followed the smoking lapse sessions on the prior evening. In terms of participants sustaining abstinence throughout the study period, 58%, 53%, and 64% of all participants in the 14C 0-puff, 14C 1-puff, and 14C 8-puff conditions, respectively, met the abstinence criterion across all 42 abstinence tests, with no significant differences between conditions.

Second, we limited the analysis to only those participants in each condition who were able to sustain complete abstinence through Days 1 to 5 prior to the start of the lapse sessions, to see if lapses might differentially disrupt abstinence for Days 6 to 14. There was no evidence that programmed lapses in the 14C 1-puff or 14C 8-puff conditions disrupted smoking abstinence relative to those in the 1C 0-puff condition. Of

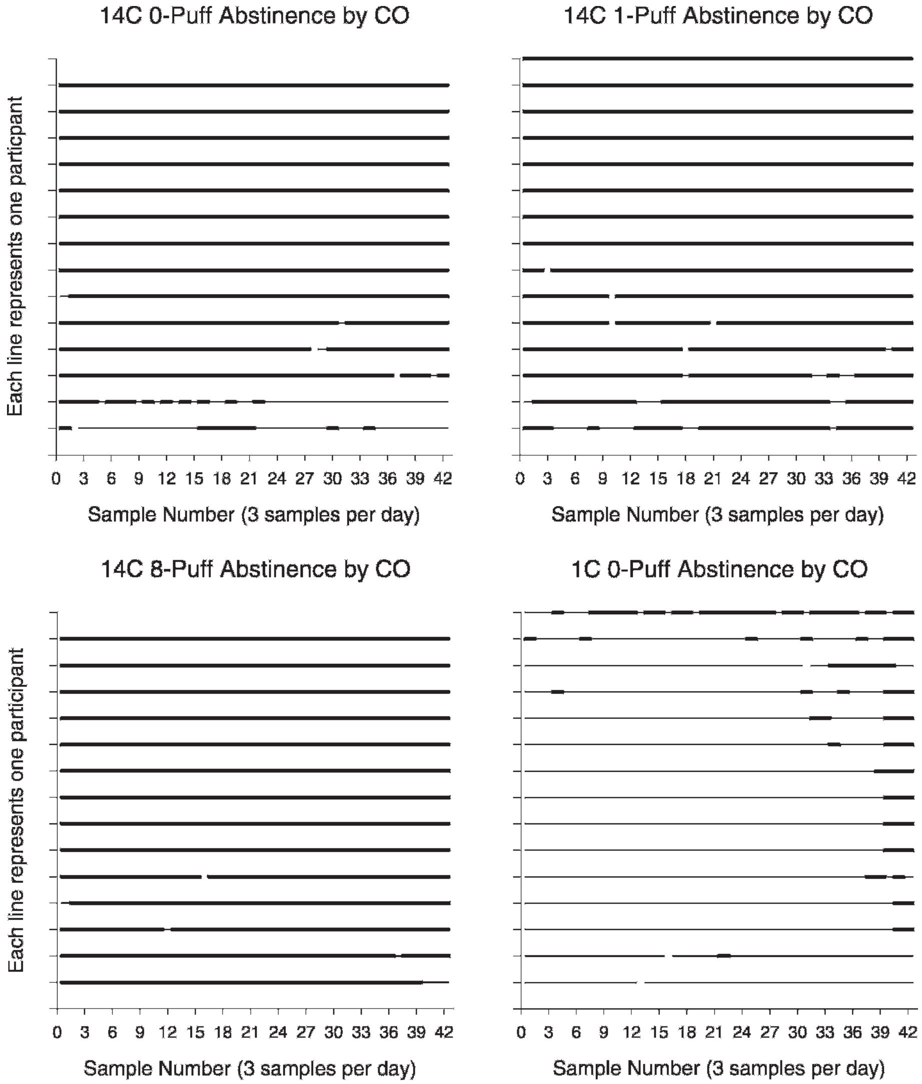

Figure 3. Shown are the number of CO samples obtained and their abstinence status across 42 consecutive CO monitoring sessions for each of the 58 participants by condition. Each horizontal line represents the breath CO monitoring results for a different individual across the consecutive sessions of the study. The solid bold portions of lines indicate that the participant provided a breath CO sample that was below the abstinence criterion at that visit. The solid nonbold portions of the lines indicate that the participant provided a breath CO sample that was above the abstinence criterion (positive for smoking) at that visit. A break in a line shows when a participant failed to provide a breath CO sample, which was counted as positive for smoking in other analyses and caused the payment schedule to reset for the next sample that was provided that met the abstinence criterion. Participants are arranged in order of abstinence rates, with those showing the fewest negative samples at the bottom and those with the most negative samples at the top.

participants in the 14C 0-puff, 14C 1-puff, and 14C 8-puff conditions, 79% (11 of 14), 67% (10 of 15), and 86% (12 of 14) were continuously abstinent during Days 1 to 5, and 73% (8 of 11), 80% (8 of 10), and 75% (9 of 12) of those participants, respectively, went on to sustain abstinence throughout the remainder of the study days.

Table 2
14C and 1C Self-Report Measures

	Days 1–13						Day 14			
	Condition				Condition × Day		Condition			
Dependent measures	14C	1C	$F(1, 55)$	p	$F(12, 669)$	p	14C	1C	$F(1, 55)$	p
Minnesota Nicotine Withdrawal Scale										
Total	6.59 (0.50)	3.94 (0.85)	7.16	**.01**	1.30	.21	5.05 (0.66)	5.58 (1.13)	0.16	.69
Visual-analogue scales										
Ease of abstaining	58.13 (3.61)	34.98 (6.13)	10.51	**<.01**	2.31	**<.01**	67.61 (4.22)	31.78 (7.18)	18.39	**<.01**
Confidence in abstaining tomorrow	74.25 (3.26)	47.81 (5.52)	17.04	**<.01**	2.50	**<.01**	75.76 (4.18)	51.70 (7.08)	8.55	**<.01**
Stimulated	41.89 (2.56)	37.84 (4.34)	0.64	.43	2.17	**.01**	44.70 (3.41)	27.92 (5.78)	6.25	**.02**
Crave a cigarette	59.08 (3.17)	34.21 (5.36)	15.93	**<.01**	1.83	**.04**	51.87 (4.77)	55.44 (8.07)	0.15	.71
Friendly	65.99 (2.23)	74.82 (3.79)	4.02	**.05**	1.19	.29	73.64 (2.36)	69.23 (4.00)	0.90	.35
On edge	30.39 (3.00)	16.10 (5.09)	5.83	**.02**	1.97	**.02**	27.51 (3.73)	30.52 (6.33)	0.17	.68
Irritable	31.86 (2.56)	16.58 (4.33)	9.21	**<.01**	1.27	.23	24.48 (3.48)	25.96 (5.90)	0.05	.83

Means (*SEMs*) are shown for each study condition for Days 1–13 and for Day 14. Significant *F* ratios are shown in boldface.

Participant Ratings

As was noted above, all participants completed various visual-analogue scales and questionnaires related to smoking abstinence, withdrawal, and mood at the final clinic visit each study day. Orderly and robust differences between the 14C and 1C conditions during Days 1 to 13 were noted on most of those participant-rated measures (Table 2), but there was no evidence of systematic effects of the programmed smoking lapses on any of them.

Participant ratings of ease of abstaining (e.g., "It was [would have been] easy to abstain from smoking today") illustrate those findings (Figure 4). Ratings in the 14C and 1C conditions were initially comparable but then increased systematically in the 14C condition across days while remaining relatively unchanged in the 1C condition, $F(12, 669) = 2.31$, $p < .01$ (Figure 4). The increases in scores over time in the 14C condition were significant, $F(1, 669) = 90.83$, $p < .01$, suggesting that participants assigned to that condition perceived the difficulty of the task of abstaining from smoking as becoming progressively easier over time, whereas no such significant changes in ratings over time were noted in the 1C condition. There was no evidence of disruptive effects of the programmed smoking lapses on these systematic increases over time in self-reported ease of abstaining in the 14C conditions.

On Day 14 when all study participants were under the abstinence-contingent reinforcement contingencies, only three participant-rated measures differed significantly between the 14C and 1C conditions (Table 2), and none were influenced by the programmed lapse manipulations. Participant ratings of ease of abstaining remained significantly higher in the 14C than in the 1C conditions, $F(1, 55) = 18.39$, $p < .01$ (Figure 4), as were ratings of confidence in their ability to abstain from smoking the next day, $F(1, 55) = 8.55$, $p < .01$, and ratings of being "stimulated," $F(1, 55) = 6.25$, $p = .02$ (Table 2).

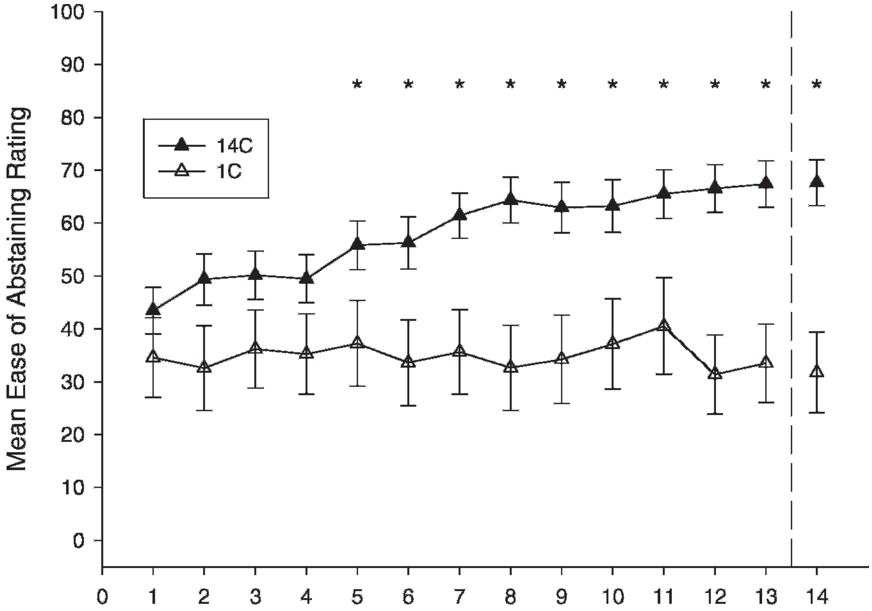

Figure 4. Visual-analogue scale self-report ratings of "ease of abstaining" are shown for the 14C and 1C conditions. Vertical dotted line between Days 13 and 14 denotes change from noncontingent to contingent payment in the 1C condition. Vertical bars represent ± *SEM*. Asterisks denote significant day-specific differences between groups for $p < .05$.

Smoking Preference Session

The smoking preference test was the only situation in which any evidence of a behavioral effect of the programmed lapses was discernible. Choice of the smoking option tended to be greater in the conditions associated with greater smoking during the 14-day study (Figure 5). Among all study participants, there was a discernible although nonsignificant trend towards greater mean number of choices of the smoking option when moving from the condition associated with the least smoking (14C 0-puff) to the condition associated with the most smoking (1C) during the 14-day study, $F(1, 54) = 1.94$, $p = .17$ (Figure 5, top). That trend became more graded in the predicted direction when the analysis was restricted to only those participants who abstained completely throughout their respective abstinence-contingent periods (i.e., 14 days vs. 1 day of biochemically verified abstinence), although it still did not reach statistical significance, $F(1, 29) = 2.55$, $p = .12$ (Figure 5, bottom).

Similar trends also emerged when percentage of participants who ever chose the smoking option were compared across conditions. Among all participants, 43% (6 of 14), 40% (6 of 15), 50% (7 of 14), and 47% (7 of 15) chose to smoke at least once in the 14C 0-puff, 14C 1-puff, 14C 8-puff, and 1C 0-puff conditions, respectively, $p > .10$ (Figure 6, top). Consistent with effects observed with mean number of puffs, a graded trend emerged when the analysis was restricted to those who sustained abstinence through their respective abstinence-contingent reinforcement conditions, with 25% (2 of 8), 25% (2 of 8), 44% (4 of 9), and 63% (5 of 8) of participants in the 14C 0-puff, 14C 1-puff, 14C 8-puff, and 1C 0-puff conditions ever choosing to smoke, $p = .10$ (Figure 6, bottom).

DISCUSSION

This study was conducted to further examine changes in the relative reinforcing effects of

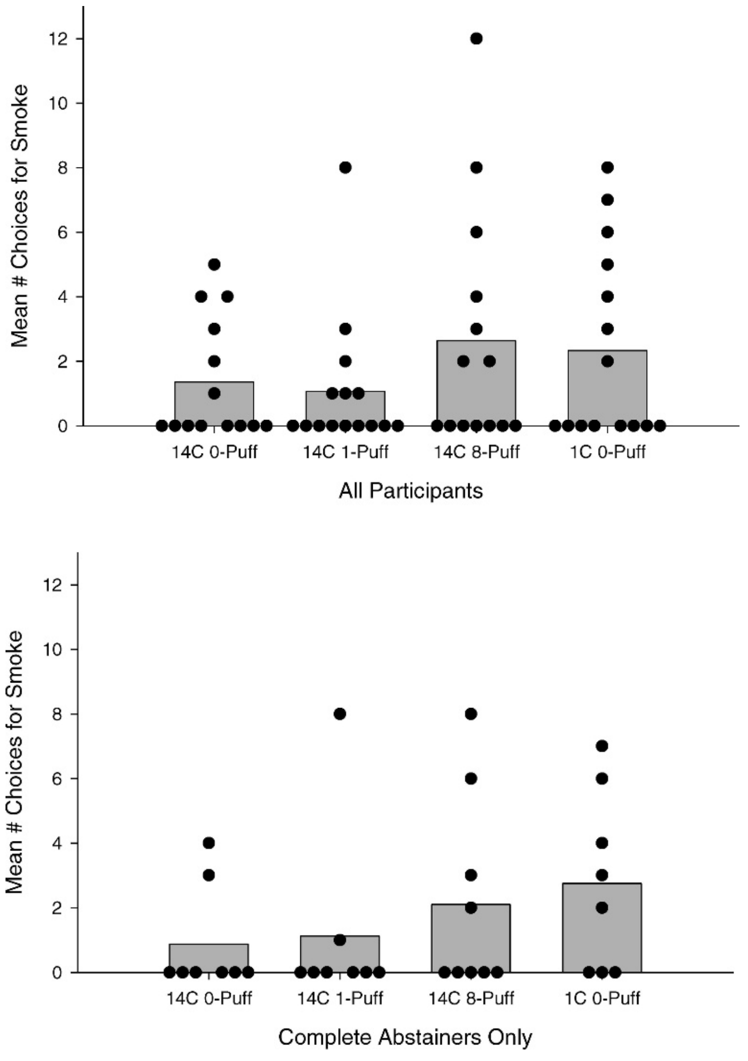

Figure 5. Shown are mean number of choices of the smoking option made during the 3-hr smoking preference session for each experimental condition. The top panel shows results for all participants (p = .17) and the bottom panel presents results for only those participants who were classified as complete abstainers (p = .12). Individual points represent number of choices for individual participants.

smoking during initial smoking abstinence by examining the influence of brief smoking lapses. As was mentioned above, gaining experimental control over smoking abstinence has been an important obstacle to conducting experimental studies that examine what dynamic changes may occur during an initial period of abstinence that may reduce relapse risk. The results from the present study and prior studies offer compelling support for the effectiveness of contingency management for surmounting that obstacle (e.g., Alessi et al., 2004; Heil et al., 2004; Heil, Tidey, Holmes, Badger, & Higgins, 2003; Lussier et al., 2005; Yoon et al., 2007). The differences in breath CO levels in the 14C and 1C conditions during Days 1 to 13 of the present study illustrated a striking degree of experimental control over smoking, a behavior that by any standard is very difficult to control for more than a few hours. Of course, the

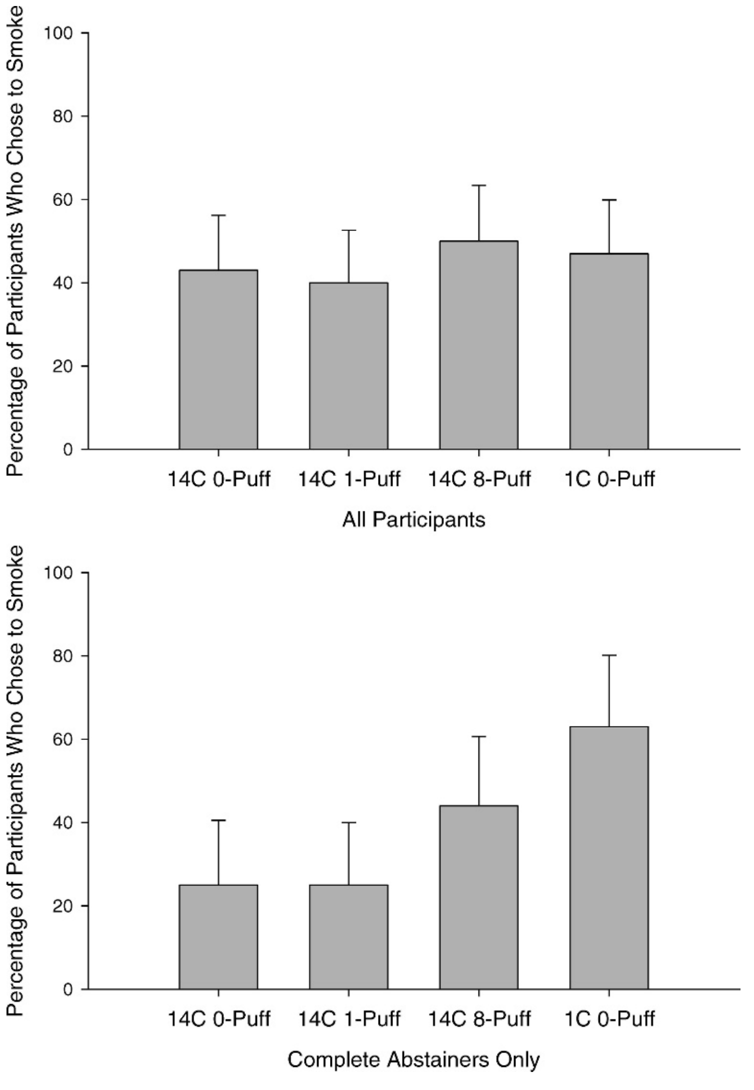

Figure 6. Shown are the percentages of participants for each experimental condition who chose the smoking option at least once during the 3-hr smoking-preference session. The top panel shows results for all participants ($p > .10$) and results in the bottom panel reflect only those participants who were classified as complete abstainers ($p = .10$). Vertical bars represent $\pm$ *SEM*.

precipitous change in CO levels between Days 13 and 14 corresponding to the change from noncontingent to abstinence-contingent reinforcement in the 1C condition further illustrated the effectiveness of the reinforcement contingencies to bring smoking under experimental control. The purpose for exerting such control in the present study was strictly scientific, but the abstinence-contingent reinforcement methods that have been developed as part of this research effort have been successfully extended to important clinical applications, including, for example, the promotion of smoking cessation among pregnant women (Higgins et al., 2004) and opioid-dependent patients (Dunn, Sigmon, Thomas, Heil, & Higgins, 2008).

There was no discernible evidence in the present study that the programmed smoking lapses disrupted control over smoking absti-

nence by the abstinence-contingent reinforcement contingencies. That is encouraging in that it suggests that regular exposure to smoking paraphernalia or brief smoking lapses need not scuttle a cessation effort when there are strong incentives to sustain abstinence, as there were with the contingency management intervention employed in the current study. Many of the difficult-to-treat populations with whom contingency management procedures for smoking cessation hold promise reside with other cigarette smokers, which makes exposure to secondhand smoke and the probability of relapse more likely (Solomon et al., 2007). The present results suggest that at least for the period while the reinforcement contingencies are in place, abstinence may still be sustainable in those populations and settings.

The results observed in the preference sessions suggest that under conditions in which the contingencies for sustaining abstinence are weaker, a history of recent lapses may increase the probability of smoking. Even though the observed changes in smoking were admittedly modest, they were very much in the predicted direction and graded in an orderly manner, suggesting that they were not likely a spurious observation. Interpreted within the context of other studies on this topic (Alessi et al., 2004; Lussier et al., 2005; Yoon et al., 2007), the results observed among abstinent participants in the 14C 8-puff condition suggest that lapses may interfere with the decreases in the relative reinforcing effects of smoking that otherwise occur from sustaining abstinence through the initial weeks of a cessation effort. That is, despite having abstained from smoking for 2 weeks, the mean likelihood of smoking in the preference test among the total abstainers in the 14C 8-puff condition was almost 1.75-fold higher than their counterparts in the 14C 0-puff and 14C 1-puff conditions and more comparable to those in the 1C 0-puff condition, who had only abstained from smoking for 1 day. We saw no difference between the 14C 8-puff condition and the other 14C conditions in participant-rated withdrawal, ease of abstaining, or other outcome measures that would provide insight into how lapses may increase smoking preference. A more detailed understanding of the mechanisms by which lapses during a period of smoking abstinence may increase relapse risk is important for the development of more effective relapse-prevention interventions.

There was no evidence in the present study of differences in smoking preference or any other measure between participants in the 14C 1-puff and 14C 0-puff conditions. Of course, participants in the 14C 0-puff condition were regularly exposed to smoking paraphernalia in the lapse sessions, even though they did not smoke. Any effect that the lapse sessions may have had on the likelihood of smoking cannot be determined in the present study due to the absence of a 14C condition with participants who did not attend lapse sessions. Indeed, in one of the two studies of which we are aware that showed an increase in relapse risk associated with exposure to programmed lapses (five cigarettes in 4 hr), denicotinized cigarettes were just as effective at increasing the likelihood of smoking as standard cigarettes (Juliano, Donny, Houtsmuller, & Stitzer, 2006). The failure to find differences between nicotinized and denicotinized cigarettes suggests strongly that the stimulus factors of smoking (e.g., sight and feel of cigarette, smell and taste of smoke) are important to any effect of programmed lapses on the probability of future smoking. Worth mentioning is that participants in the Juliano et al. study also received monetary incentives to sustain abstinence, but at a daily magnitude that was only approximately one fourth or less of that used in the present study. Also, magnitude was reduced over time, rather than increased as in the present study, in order to increase the likelihood that participants would smoke.

In the one other study in which programmed lapses increased subsequent smoking, there were no programmed monetary incentives for sus-

taining abstinence, and participants were not trying to quit smoking long term, suggesting little immediate naturalistic reinforcement for sustaining abstinence following exposure to the programmed lapses (Chornock, Stitzer, Gross, & Leischow, 1992). Considering results across the present and the two earlier studies, the effects of lapses on the future probability of resuming smoking appear likely to depend on whether and at what amount reinforcement for sustaining abstinence is available.

Results from the participant rating scales in the present study failed to show any effects of programmed lapses, but otherwise replicated previous findings from our laboratory showing dynamic changes in the 14C conditions compared to the 1C condition during the initial 2 weeks of abstinence that are consistent with a lowering of relapse risk (Alessi et al., 2004; Lussier et al., 2005). The most consistent observation across the present and prior studies is that participants rated the challenge of abstaining from smoking as progressively easier as the duration of abstinence increased. As noted previously (Lussier et al.), lower response effort has been demonstrated in basic and applied research to increase the probability of responding (Friman & Poling, 1995). To the extent that abstaining from smoking can be considered an operant response or task (which we believe is clearly supported by the present results), a history of successfully abstaining coupled with a progressive increase in the perceived ease of abstaining could reasonably be expected to be associated with an increase in the probability of sustaining abstinence in the future. In population surveys of current smokers, perceived difficulty associated with quitting appears to deter smokers from attempting to quit (Mullins & Borland, 1996). In addition to observing increases in self-reported ease of abstaining, the current study replicates previous findings indicating that ratings of confidence in abstaining tomorrow increase with increasing abstinence, and withdrawal and craving peak in the initial days of abstinence and then decrease over the course of a 2-week period of sustained abstinence. Any or all of these dynamic changes during the first 2 weeks of abstinence might conceivably facilitate longer term abstinence.

Overall, the present study provided further evidence that supports the effectiveness of contingency management interventions to exert robust control over cigarette smoking in the natural environment, while also illustrating further their utility as a research tool in addition to a treatment intervention. Results on the influence of programmed smoking lapses revealed no disruptive influence while reinforcement magnitude for sustaining abstinence was relatively high (e.g., \$3.00 to \$10.00 per session for abstinence during abstinence monitoring) but at least limited disruption when the magnitude was lower (e.g., \$0.25 per choice during the smoking preference sessions). Results also support those from prior studies suggesting that a period of sustained abstinence during the initial weeks of abstinence results in changes that likely lower relapse risk.

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